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The conceptual framework for estimating food energy requirement

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Abstract

Objective: In anticipation of the revision of the 1985 Food and Agricultural Organization/World Health Organization/United Nations University (FAO/WHO/UNU) Expert Consultation Report on 'Energy and Protein Requirements'[1], recent scientific knowledge on the principles underlying the estimation of energy requirement is reviewed.
Design: This paper carries out a historical review of the scientific rationale adopted by previous FAO/WHO technical reports on energy requirement, discusses the concepts used in assessing basal metabolic rate (BMR), energy expenditure, physical activity level (PAL), and examines current controversial areas. Recommendations and areas of future research are presented.
Conclusions: The database of the BMR predictive equations developed by the 1985 FAO/WHO/UNU Expert Consultation Report on Energy and Protein Requirements needs updating and expansion, applying strict and transparent selection criteria. The existence of an ethnic/tropical factor capable of affecting BMR is not supported by the available evidence. The factorial approach for the calculation of energy requirement, as set out in the 1985 report, should be retained. The estimate should have a normative rather than a prescriptive nature, except for the allowance provided for extra physical activity for sedentary populations, and for the prevention of non-communicable chronic diseases. The estimate of energy requirement of children below the age of 10 years should be made on the basis of energy expenditure rather than energy intake. The evidence of the existence of an ethnic/tropical factor is conflicting and no plausible mechanism has as yet been put forward.

Keywords
Basal metabolic rate
Energy requirement
Physical activity level
Predictive equations
Ethnic factor
Tropical populations
Physical activity
Adaptation

Introduction and historical overview

The first attempt to establish human energy requirement at population level was carried out by FAO in 1950[2]. The conclusions reached were considered to be of a provisional and tentative nature, given '... the existing state of knowledge.' Lack of sufficient information made it impossible to adopt a factorial approach. The factorial approach estimates total energy requirement on the basis of the summation of the various components of energy expenses. Therefore, requirements were equated to the observed energy intakes of various population groups. Hence, the approach based on the energy intake of a 'reference standard' was adopted. It was clearly stated that such estimates were applicable only to groups and not to individuals. Reference man, woman, and child were created, with defined patterns of physical activity, body size and age, and their mean daily energy requirement was calculated. Equations were provided for adjustment of the reference individuals' energy requirement on the basis of the weight and age of the adults. These adjustments were not to be applied to children, in order to allow for possible catch-up growth. Adjustments of the reference individuals were to be made for the specific subpopulations, such as extra energy needs for pregnancy and for lactation, and correction factor for climate. Adaptation to chronic energy undernutrition was recognised to exist in adults, however it was deemed to be neither desirable nor cost-free, thus no adjustment in the calculation of energy requirements was to be made for it. The energy requirement was intended to be expressed as food energy, based on the specific Atwater factors.

In 1957, the second expert consultation meeting on energy requirements[3] basically maintained unmodified the earlier approach, but refined somewhat the underlying concepts and definitions. Recommendations were issued with slightly greater confidence, but they were still considered to be only tentative and provisional. The committee highlighted a number of issues that required urgent research in order to improve the estimation of the energy requirement, such as the needs for pregnancy, information on cost of physical activities and the allocation of time to different pursuits, the influence of climate and ageing.

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In 1973, FAO and WHO undertook jointly to revise the energy requirements and an *ad hoc* committee of experts was appointed, this time to address also the protein needs[4]. The factorial approach for the estimate of energy requirement was endorsed for the first time. The committee retained the concept of the 'reference man' and reiterated that energy requirements are applicable to populations or appropriately large groups of individuals, but not to individuals. It also reiterated the concept that, for energy, the needs of a group correspond to the average of the requirements of the individuals, and specifically rejected, as not applicable to energy, the 'safe level' approach adopted for protein. It redefined the 'reference individuals' amplifying the specifications.

Categories of energy requirements were refined by introducing several occupational categories suitable to describe diverse populations, specifically taking into account developing countries' lifestyles and conditions. Adjustments for size of adults were recommended; tables of reference values (but not 'norms') for heights and weights of children and adolescents were provided in the appendix of the report, for adjustment of their requirements. Emphasis was placed on the need to refer to 'healthy' populations for establishing the reference data. It was specified that populations with high prevalence of obesity – as was the case for several of the industrialised countries for which intake data were available – were not to be used as references. It was also noted that developing countries' populations were unsuitable to serve as references, being at risk of 'adaptation' to a low plane of nutrition by reduction of their body size and, possibly, a decrease of their physical activity. At that time, the expert committee stated that estimates of energy requirements should be based as far as possible on estimates of energy expenditure. It was, however, acknowledged that most of the recommendations on energy requirement had to be based, for lack of energy expenditure data, on food intake data[4] (page 24). The committee also felt that – for the purpose of assessing energy needs – data on energy expenditure were no more informative than dietary surveys, and the attention was drawn to the many possible technical errors and methodological limitations of the measure of energy expenditure. A rough classification of work categories was provided with a listing of the occupations falling in four categories of light, moderate, very active and exceptionally active. Attention was given to the minimal amount of physical activity required to maintain long-term health (cardiovascular, respiratory and muscular) and to prevent obesity. Energy expenditure was related linearly to body weight, and it was suggested that the cost of activities should be expressed as $\text{kcal}\,\text{kg}^{-1}$ body weight. Correction for optimum weight for height, possibly corrected for the proportion of body fat, was considered desirable but it was regretted that it would be difficult on the basis of the information available to quantify it. As for the climate adjustment, the lack of a reliable quantifiable basis for correcting energy requirements brought to the conclusion that the latter should be adjusted only if there was a measurable effect of environmental factors on physical activity.

Conceptual framework of 1985 FAO/WHO/UNU report

The fourth and most recent expert consultation meeting met in 1981 to discuss and update energy and protein requirements and the report appeared in 1985[1]. It was jointly convened by FAO, WHO and UNU, and it defined energy requirement as '*the level of energy intake from food that will balance energy expenditure when the individual has a body size and composition, and level of physical activity, consistent with long-term good health; and that will allow for the maintenance of economically necessary and socially desirable physical activity*'.

The experts of this committee retained most of the general approaches of the previous consultations, but some substantial progress was made, principles were redefined, issues highlighted and approaches innovated. These changes and refinement were made possible by the accumulation of an appreciable amount of new information in the area of energy metabolism that had been stimulated by the publication of the 1973 report on energy requirement. Studies and surveys had produced a wealth of documentation that provided scientific support to approaches and principles previously adopted on rather inconsistent ground, or led to reject others that failed to be confirmed or proved wrong. These are discussed in detail in the following sections.

The basic principles

Energy requirement to be based on energy expenditure, not energy intake

The first important change to be introduced was that energy requirement should be estimated on the basis of energy expenditure and not of energy intake. This concept is not new, as it had been recognised since the first attempt of FAO in 1950 to define energy requirement, although its adoption had not been possible for dearth of data on energy expenditure[2]. The concept recognises that it is energy expenditure that drives energy needs rather than intake, which does not necessarily reflect the energy needs and may vary independently. Indeed, positive energy balance can be sustained long term without leading to any adjustment of energy expenditure. As energy cannot be disposed of, all excess is inevitably accumulated in the body as fat. In 1980, despite the adoption of this concept, information on energy expenditure was still scarce, and it was necessary to rely, under certain circumstances and to a certain extent, on energy intake data. In particular, lack of information on energy expenditure of children aged less than 10 years obliged the retention of an approach based on the estimation of energy intake. A further complication in the application of the energy expenditure approach to adults was the need to exercise a value judgment, given that the available observed levels of energy expenditure might be the outcome of a process of adaptation to chronic energy deprivation rather than expression of a freely chosen, unrestrained lifestyle. This consideration is particularly relevant to developing countries, where food availability may be seasonally insufficient or in other circumstances where food insecurity is present. Under these conditions, energy intake does not match energy expenditure, and a series of process are set into motion, of which a decrease in energy expenditure represents a major one[5]. This concern is reflected – in the current definition of energy requirement – in the specification that the level of physical activity should be *compatible with long-term good health; and allow for the maintenance of economically necessary and socially desirable physical activity.*

Scope for adaptation of energy requirement

The potential of humans to adapt to low energy intakes had attracted huge attention in previous years, and had been amply and hotly discussed. New evidence had been gathered, and thus the concept of adaptation figured prominently in the 1985 report, as recommended by the informal gathering of 1978[6]. Adaptation was defined as '*a process by which a new and different steady state is reached in response to a change or difference in the intake of food or nutrients*'. The limits of human adaptability and the detrimental vs. advantageous changes were debated, and the need to exercise value judgments when assessing energy requirements was recognised. The range, limits and possible associated functional or societal costs of human adaptation were considered, and adaptation was seen as a factor capable of substantially modulating the requirement of energy, for example by a decrease in body size. Three different routes of adaptation processes were recognised, namely metabolic, biological/genetic, and social/behavioural. The outcomes of adaptation most relevant for energy requirements were considered to be alterations in body size and a decrease in physical activity. A change in the metabolic handling of energy at the cellular level was considered conceptually very important for its potential policy implication, but quantitatively rather modest. The conclusion was that the evidence necessary to quantify the phenomenon was still insufficient.

Energy requirements estimates refers to groups, not to individuals

Another basic principle that was re-confirmed in the report was that the estimate of energy requirement refers to groups and not to individuals, and that the only thing that can be said about the individuals in the group is that there is a certain, but *not quantifiable,* probability that their individual energy requirement falls within the variance of the mean requirement of the group. This probability approach, useful when assessing the adequacy of the mean group energy intake, has limitations (see later). Groups were defined as consisting of a number of individuals with similar attributes that are known to influence their energy expenditure, namely age, sex, physiological conditions such as pregnancy, physical activity and body size. Obviously, the similarity of individuals within a group may be more or less tight. The tighter the similarity, the smaller the inter-individual variance of the groups' energy requirement but lesser the possibility of extrapolation of the results to other groups. A certain degree of mediation is required, and the need to strike the right balance between approximation and general applicability. It was noted that an estimate of the variance of the energy expenditure within and between individuals composing a group represents a major element for the application and interpretation of estimates of energy requirement (see section on probability approach), but that information on the intra- and inter-individual variance of energy expenditure was very scarce at the time of the 1980 expert consultation meeting, and mostly limited to developed countries.

Energy requirement of a group is the mean of the group, and includes no safe margin

The third concept on which the estimation of energy requirements was based was that – different from protein and all other nutrients where a safe margin corresponding to two standard deviations above the physiological needs is included to specify the requirement (or recommended dietary allowance, or population reference intake (PRI)) – the requirement for energy refers to the mean requirement of the group or population, and represents the average of the needs of all individuals composing that specific group. This construct recognises the fact that excess energy cannot be disposed of and is accumulated in the body as fat, with the long-term undesirable outcome of obesity. This position had been adopted since the first report on energy requirements[2], and no good reason was found to modify it.

Rejection of the concept of 'reference man'

A major change in the 1985 report from previous reports was the rejection of the concept of the reference individual. A more flexible approach was adopted to allow space for the ample diversity that exists in real life, and to consent a better tailoring of the estimate of energy requirements to the specifics of each circumstance. Thus, for example, the physical characteristics of the groups needed not to be adjusted to reflect the body size of the reference individual, but would rather reflect the actual sizes of those individuals or values that are judged as appropriate for the specific circumstances. The adoption of this approach removed the rigidity of the reference man concept but left a larger space to the arbitrariness of value judgments. It also detailed the extra energy needs of pregnant and lactating women and of children.

Requirement for what? Normative vs. status quo

The rejection of the 'reference' individual approach allowed the process of estimating energy requirements to reflect more closely the complexity of real life. However, it also created the necessity, each time the energy requirement of a group was estimated, to make a judgment about the lifestyle profile, and of the associated physical, functional and health attributes. In other words, the question 'requirement for what?' came to occupy a central position in the assessment, placing a greater responsibility on the user's knowledge and understanding of pertinent energy facts and associated health implications, as well as on the need to adopt specific judgmental values considered appropriate to local conditions, priorities and applications. Thus, complex and delicate judgment is required to decide whether to allow for the extra energy that is needed for stunted children to catch up in their growth, or whether the desirable body weight should be the basis for calculating the energy requirement of a community where adult obesity is highly prevalent. The same applies to situations where infectious diseases and intestinal parasites are endemic, as often occurs in developing countries, and thus are likely to appreciably increase the energy requirement, especially of young children. And also, is it justified to allocate extra energy to allow for physical exercise for long-term health and fitness to be undertaken in currently sedentary communities? The latter decision was in fact endorsed by the committee for 1–10 year children of industrialised countries, whose energy requirement – based on current energy intake – was raised by 5% to ensure a desirable level of physical activity. No explicit advice was issued by the committee as to the 'when' and 'to what extent' the *normative* or the *status quo* requirement should be applied. The report, as the only guidance in this complex judgment, advised that the decisions taken should be as transparent as possible.

The adoption of the factorial approach and of the expression of multiples of BMR

The major innovation in the 1985 report was the expression of energy requirement/expenditure, as well as its various components, as multiples of BMR. The adoption of this approach was driven by the consideration that BMR represents the largest component of energy expenditure, which, in a sedentary style of life, can be as high as 70%. It also has the benefit of having a very small intra-individual variability, of about 3%, thus making it a very reliable biological parameter. The main argument produced in favour of this change was that expressing energy expenditure/requirements in terms of BMR factors makes it unnecessary to correct for body weight, thus simplifying the calculation and allowing easier and more meaningful comparisons among diverse population groups. The report, however, recognised that a residual variability of BMR kg^{-1} body weight remained at the diverse weights and different ages, with higher values per unit body weight for smaller individuals than for bigger ones. These differences would be amplified by the calculation of total energy expenditure by means of multiples of BMR and could result in an overestimation of the energy expenditure/requirement of smaller people and an underestimation of the larger ones. Despite these inconsistencies, that were not quantifiable at that time, the convenience of expressing energy requirement in terms of multiples of BMR was considered such that this formulation was proposed. Indeed, this expression has since been widely adopted.

The factorial approach consists in the summation of the various items representing the energy expenses, such as the costs of the diverse types of physical activity undertaken, the extra energy allocated for pregnancy and lactation – if appropriate – and the energy cost of growth. The importance and social desirability of 'discretional activities' was recognised and for the first time the need was highlighted to take them into proper account when estimating the energy needs of a group. A minimal level of physical activity was considered essential for long-term maintenance of cardiovascular health and of muscular strength, but the quantification of this level was ill defined, and it took the form of a generic, tentative advice rather than a firm recommendation.

No adjustment for climate/altitude

While it was acknowledged that exposure to climatic extremes might affect BMR as well as physical activity, the evidence that communities living in a very hot or very cold climate are indeed exposed to these temperatures to the extent that their physiology and/or behaviour is modified was not available. Therefore, no adjustment of energy requirement was deemed necessary for extremes of climate and/or altitude. However, it was noted that the subject warranted further investigation.

New reference values for BMR

The new approach of expressing the various components of energy requirement/expenditure as multiples of BMR, made it imperative that valid BMR be used. However, it was recognised that only under ideal conditions, BMR would be directly and reliably measured, and it was anticipated that, for practical reasons, BMR would be derived in most cases from the literature. A variety of predictive equations have been available for a long time, but a validated and unified set of equations was needed to obtain consistent results. Therefore, appropriate predictive equations were developed and adopted by the 1985 expert committee based on a rigorous selection and analysis of all available data sets. About 11 000 BMR data were screened and a set of equations was specifically developed for the prediction of

BMR from body weight, with or without height factored in, at different ages and sexes. These equations were proposed as being '... the best estimates at present available for predicting the BMR of healthy people in any population.'[1]. These equations are age and sex specific, and use body weight as independent variable. Height was found not to contribute significantly to the predictive power of the equation, except for a small effect in children aged 0–3 years and the older age classes. The FAO/WHO/UNU analysis was followed after a short interval by another in-depth statistical analysis of the same data bank with only minor changes (some data were excluded on technical grounds or bias of sample), and a new set of predictive equations was published – henceforth defined as Schofield equations, which were, however, only marginally different[7].

The probability approach

The report established that the estimate of the energy requirement does not allow conclusions to be drawn relative to the adequacy of the energy intakes of any given individual. It can only provide an estimate of the likelihood that a proportion of the individuals in that group will over- or under-consume energy relative to their needs. According to this approach, the smaller the difference between the two averages – the estimated requirement and the measured intake – the smaller the likelihood that any of the individuals of the group has too high or too low an intake. The larger the difference the higher the probability that a larger proportion of the individuals have inadequate intake. The report was, however, unable to give a quantitative estimate of the prevalence of inadequate or excessive consumption, given the limited knowledge of the variance of the requirement as well as of the strength of the correlation between energy intake and energy expenditure.

Baseline/survival energy requirement and maintenance requirement

A *survival*, or baseline, energy need was set at 1.25 × BMR, applicable only under crisis conditions and defining the short-term needs of totally inactive and fully dependent people. However, such a low value was considered too low to be applicable except under very exceptional conditions. Thus, an attempt was made to establish also a more realistic *maintenance* requirement that would describe very sedentary lifestyles, and would allow the minimum of self-reliance. Evidence was lacking to recommend this specific level, and given the highly subjective component of what would represent a maintenance level of physical activity, only a tentative figure of 1.4 × BMR was suggested, with the indication that it should be reviewed when new evidence became available.

International Dietary Energy Consultative Group 1996 and changes proposed to the 1985 framework

In 1994, taking into account the notable progresses in the field of energy studies, such as the methodological development in the measurement of free living energy expenditure (doubly labelled water, DLW) and the accumulation of an ample body of new information in the area on energy metabolism and expenditure over the past several years, the International Dietary Energy Consultative Group (IDECG) undertook to review the 1985 WHO/FAO/UNU report[8]. The review re-examined the general principles and approaches that had been adopted in 1985, for defining the energy requirements of the adult, of the infant, of children and adolescents, of older individuals and of pregnancy and lactation. While it was established that the main body of principles adopted by the FAO/WHO/UNU report were still largely valid, the new information available made it possible to rectify some of the basic principles, query some others, and suggest some new approaches.

Main issues considered

The first consideration regarded the basic principle that energy requirements must be established on the basis of energy expenditure and that it refers to groups rather than individuals. This principle was fully endorsed, as was the use of multiples of BMR for the expression of energy requirement and expenditure, recognised as convenient and simple[9].

The IDECG experts noted that the newly developed methodology for measuring energy expenditure in free-living individuals, DLW, had generated information on the energy expenditure of about 1100 individuals aged 2–90 years. These data were carefully reviewed and, for adults, it was found that there was a surprisingly good agreement between the theoretical calculations of the energy expenditure levels of the three work categories of the 1985 report, and the actual values recorded by DLW, with physical activity level (PAL) of light work at 1.55 for man and 1.56 for woman, the moderate one at 1.78 and 1.64, respectively, and the heavy work category at 2.10 and 1.82 for man and woman, respectively.

A major innovation regarded the estimate of energy requirements in children, as it was felt that a considerable body of new information had been accumulated over recent years on their energy expenditure, by the DLW or the heart rate method. On this basis it was proposed that children's energy requirement should be derived on the basis of expenditure data rather than energy intake, similarly to the adults, unifying the procedure of expressing their energy requirement as multiples of BMR, or PAL[9].

The concept of *maintenance* energy requirement – at a PAL of 1.40 – was retained. However it was stressed that this value was acceptable only because it was felt that there was still insufficient new information for revising it. Also the 'survival' PAL, set at 1.20 in the 1985 report, was confirmed, as very similar values had been obtained by DLW in 'chair-bound' or bedridden individuals. Finally, the inclusion, in the calculation of energy requirement, of a minimum level of physical activity for the maintenance of physical fitness and cardiovascular health was endorsed, and specified as 30–60 min vigorous exercise four to five times per week. This frequency and intensity of exercise was calculated to elevate a sedentary PAL of 1.6 by about 0.3 PAL[10]. However, it was also stated that a proper revision of the literature needed to be undertaken to provide a sound, science-based advice on the type, level and duration of exercise to be recommended.

A detailed, exhaustive and updated review of the mechanisms of human adaptation to energy imbalance brought the final word on this aspect and the related need to account for it in the calculation of energy requirement[10]. A distinction was drawn between short-term or acute homeostatic regulatory response and long-term mechanisms of adaptation. The metabolic changes induced by variations in energy intake were examined in detail, and considered to be only a short-term response. Any long-term apparent modification of the metabolic efficiency of energy handling was considered to be probably the outcome of covert changes in the composition of the fat and fat-free compartment of the body. The behavioural form of adaptation, consisting in saving energy by decreasing the level of physical activity, was taken to be the most likely – as well as the most efficient – adaptive response. These considerations were then linked to the need to define what is meant for 'desirable' in terms of levels of energy expenditure and of body size and composition, and whether the estimate of energy requirements should be of a *status quo* or of a normative nature. It was noted that a normative approach is required when the decision is made to allow for catch-up growth to occur in stunted and underweight children, and for the return towards the normal range of overweight and underweight adults. For what concerns physical activity, the normative approach should to establish whether a low plane of physical activity is expression of a sedentary life-style, or the expression of adaptation to insufficient energy intake. The second option involves undesirable biological and societal costs associated with all forms of adaptation, and it was suggested that no allowance for adaptation should, therefore, be factored in the estimation of energy requirement. However, the normative approach requires that sound scientific evidence be made available to specify the 'desirable' biological dimensions and behavioural and societal context, and it was noted that such information was still lacking.

Much attention was paid to review the BMR data, given the dependence of the estimation of energy requirements from a valid BMR value. Methodological aspects were raised, but it was agreed that, when properly measured, BMR has a small intra-individual variability – coefficient of variation (CV) about 3% – and remains constant over time. However, the existence of large inter-individual variability was confirmed, and a vivid illustration of the implications was provided by calculating that the range of variation for a group of adults would be approximately 500 kcal day^{-1} for the documented CV of measured BMR of 8%[12]. The causes of this variability of BMR was reviewed, but remained unclear. Part of the problem appears to be related to body composition, especially at the two extreme of fatness or leanness. However, the issue is confounded by the mechanical efficiency of movement in the case of obesity, and the complex changes in the proportion of organs and tissues composing the fat free mass (FFM) in the very lean subject adapted to low energy intake. The bottom line however was that the major cause of the wide inter-individual variance appears to be related to the simplistic approach to normalise BMR on body weight, assuming that the relationship is linear.

When BMR is predicted, as it occurs most often, the uncertainties increase. The validity of the existing predictive equations[1] was questioned and their limitations reviewed. The scarcity of the data for certain age classes such as infants, children, adolescents and the elderly was noted[11]. A second limitation was the almost total lack of data from developing countries. A third point was made about the need for more stringent quality criteria in the selection of the BMR data from the literature, with full assurance that only BMRs measured with strict care and rigorous respect of appropriate experimental procedures were included. The fourth concern was the possible existence of an ethnic and/or geographical factor capable of affecting the BMR. Indeed, the Indian BMRs that had been included in the Schofield data bank were 10–11% lower than the age, sex and weight-matched European and American counterparts. It had been argued that this might reflect a concomitant condition of undernutrition, but lack of information made it impossible to reach a conclusion. The IDECG meeting thoroughly reviewed this subject and noted that a number of papers had been published that pointed to a tendency of the Schofield predictive equation to overestimate the BMR of several, but not all, tropical populations, and also of some western populations, e.g. Australians, North Americans. The Schofield database included a disproportionate presence of Italian subjects, with a significantly higher BMR compared to the total sample. These data appeared to introduce a bias in the sample, and might be responsible for the tendency of the Schofield equations to over-estimate BMR by 7–10%[12]. IDECG, therefore, commissioned an update and expansion of the original Schofield database, indicating that strict, transparent and objective quality criteria of data inclusion should be applied; new BMR predictive equations were to be developed, taking into account factors such as body size and composition, stature, ethnicity, climate.

The IDECG report also lamented the dearth of information on the type, duration, pattern and related energy costs of physical activities under true-life conditions, especially in developing countries and involving manual labour. It underlined the importance of greater clarity on the circumstances under which physical activities are undertaken and whether the measured costs refer to the 'net' task or include rest pauses and/or the mixtures of activities that are needed to accomplish a given task. Methodological issues were also emphasised as it was felt that the number and representativity of subjects on which the energy expenditure measures were performed had been often unsatisfactory, with sometimes 'ridiculously' small numbers of subjects and/or measurements. It was also felt that the majority of the study samples were highly biased, with an over-riding presence of westerners, often university students or other unrepresentative and highly selected individuals. The extrapolation of the information gathered on these samples to other groups, and especially to underdeveloped populations, was reputed to be of doubtful validity.

A large body of evidence had also been accumulated on the energy requirements of pregnancy and of lactation, on the energy cost of child growth. These allowed a detailed review of the energy costs of the various components of the biological process, and to confirm the factorial approach as the appropriate one for the estimate, while rectifying some of the values that had been assigned to these processes. Also, new information was available on the energy expenditure of elderly people, mostly measured by DLW and on children, assessed by Heart Rates Monitors.

One paper[11] made a strong point about methodological issues related to the measures of energy intake and expenditure, and underlined the limitations of the DLW method, for the purpose of estimating energy requirements. It was felt that this method did not provide useful information, unless associated with the collection of data relative to the use of time and lifestyles of the subjects. It also stressed that recourse to published values of energy costs of activities could be very misleading unless it was very clear whether these costs referred to 'pure' tasks, meaning that a precisely defined activity is undertaken, or an 'adultered' cost, meaning that it integrated the pauses for rest and/or the entire mix of accompanying activities, such as usually occurs under true life circumstances when undertaking a job. The paper makes a strong plea, shared by Shetty *et al.*[10], for the collection of additional and better quality documentation on these aspects.

Recommendations

Overall, the IDECG meeting endorsed the principles and approaches of the 1985 report[1]. It also took note of the considerable accumulation of new information that had become available in the intervening years and suggested, on this basis, some changes. The most notable recommendations were to use energy expenditure to estimate the energy requirement of children rather than energy intake, and the firm rejection of allowing, in the estimate of energy requirement, for any form of adaptation to low energy intake.

A brief summary of the several specific recommendations of changes or improvements is presented in Table 1.

Discussion

The overview of the 1985 FAO/WHO/UNU report, and of the 1996 IDECG update, indicates that, while the principles and concepts adopted in these two reports are still valid overall, some improvements and changes are warranted. The position adopted by the IDECG meeting and its recommendations can be shared, but it is worth considering that at least 5 years have elapsed since the meeting took place. A number of papers have appeared in the literature that made valuable comments and criticisms. To be fair, most of these papers and studies have indeed been stimulated by the explicit reference to specific problems raised by the two above mentioned reports. Among the most pressing issues granted priority attention are the problem of the reference values of BMR and the relative predictive equations, the nature and causes of inter-individual variability of BMR, the nature of the relationship between body size and energy expenditure, the 'desirable' level of physical activity for health promotion and maintenance, and the dearth of information on current prevailing profiles of time use and energy expenditure, especially in developing countries. Progress in understanding these issues has indeed been recorded, but it appears that in most cases, a solution of the problems has not yet been reached.

The BMR predictive equations

The issue of BMR has indeed caught most of the attention of researchers worldwide, both because of the need to fill the gap of data for certain age groups and for developing country populations, as well as for the emerging

Table 1 Main recommendations issued by the International Dietary Energy Consultative Group Energy and Protein Requirement workshop[8]

- Estimates of energy requirements of children below 10 years to be made on the basis of energy expenditure.
- The need to review the maintenance energy requirement of 1.4 × BMR, as well as the specified multipliers of BMR for the three occupational categories, while maintaining them for the time being.
- More information is needed to better describe time, duration and energy costs of physical activities.
- The 'desirable' body mass and level of physical activity needs to be defined and scientifically supported.
- No allowance to be made for adaptation.
- Better quality control for the methodology used for measuring energy expenditure and the selection of appropriate study samples were stressed.

importance of an alleged ethnic or tropical climate factor. Thus, not only several laboratories of established competence in energy metabolism research, but also laboratories and researchers that had not previously engaged in this type of research, have undertaken to measure the BMR of various population groups. A first consideration that can be made on the newly available data is that not all of these appear to have the level of quality assurance that had been specifically recommended by the IDECG meeting[11]. For example, extravagantly wide ranges of BMR of normal healthy individuals, 6.32–12.50 MJ day^{-1} for young males and 3.46–8.74 MJ day^{-1} for middle aged women[13], have been published without providing an interpretation or a justification, and inevitably raise some doubt as to their validity.

BMR has a pivotal role in the estimation of energy requirement. Not only does it represent the largest component of energy expenditure, but also its importance is further amplified when energy requirement is expressed as a multiple of BMR. The simplicity, the convenience for comparison across populations with diverse levels of physical activity and attributes of age, sex and body size, and the ease of interpretation of the results has made it immensely popular. These advantages however have tended to obscure its inherent limitations. These limitations were acknowledged in the 1985 report, such as the dearth of BMR data relative to certain age classes and to developing countries' populations. But other problems have emerged later on, consisting of an apparent systematic overestimation of the BMR of tropical populations. As firstly pointed out by Henry *et al.*[14] and later confirmed by others[15], the measured BMR of Asians, Africans and South Americans appears to be consistently lower than that of age, weight and sex-matched Westerners. Their BMR is systematically over-predicted by about 5% (women) to 9% (men). Two distinct, but allied and concurrent reasons for this phenomenon have been suggested, the first one incriminating a bias of the data bank used to develop the Schofield predictive equations, the other rooted in an alleged ethnicity factor proper of populations living in the tropics.

The database

The first of these two reasons is grounded on the fact that about 50% of the BMR data from which the Schofield equations were developed consist of Italian subjects. Indeed, their BMRs are distinctly higher than those of the rest of the groups, Westerners included, mostly for adult males, less for adult females, and even less for children. Their higher values do appreciably influence the derived predictive equations. However, the Italian BMRs had been included in the data set because the original screening had found no technical fault that justified their rejection[16]. Two reasons have been advanced by Henry to explain the high BMR values of the Italians, which would justify their rejection, namely faulty methodology, and the dominant presence of selected highly trained and physically fit individuals from the army[15].

In order to clarify these aspects, and in order to confirm the legitimacy of the rejection of these data sets, a re-visitation of this Italian data set was warranted. Thus, given the advantaged access of the present author to the published papers – in Italian – a thorough review of the original documents was conducted by the author of this paper, and is presented below.

The original raw data of a sample of 1739 males, aged 18–30 years, was extracted for this purpose from the Italian data set. These were measured in the late 30s and early 40s, as part of a vast, nationwide multi-centre survey promoted by the Italian National Research Council[17–22]. None of these papers claimed that the samples were nationally representative; nevertheless, a rather wide variety of individuals, job denominations, and geographic derivations were included. Indeed, none of the other data sets included in the Schofield data bank was even nearly as varied. An in-depth scrutiny of the methods described in the papers reveals a very thorough inter-team standardisation of procedures, a meticulous description of techniques, the application of scrupulous checks (such as continuous monitoring of heart rate and pulmonary ventilation rate throughout the measurements), the systematic rejection of duplicates that differed more than 2 kcal m^{-2} of body surface. The assumptions relative to the value of respiratory quotient (RQ, not measured), the calorific value of oxygen, the formula used for calculating body surface were all clearly stated (see Table 2). The closed-circuit method was employed, as was most common practice in those years. If competently used (i.e. avoiding losses of O_2), all other features of the closed-circuit tends to give lower rather than higher values of oxygen consumption. Hence, this analysis could not identify any apparent methodological flaw, thus it is concluded that these data cannot be rejected on this ground.

Table 2 Methodological details of the measurement of BMR of the Italian subjects[23] included in the Schofield database[16]

Energy expenditure = $VO_2 \times 4.825$ (assuming an RQ = 0.825)
BMR expressed in kcal m^{-2} h^{-1}
Calculation of body surface: $71.84 \times W^{0.425} \times Ht^{0.725}$ (Du Bois, 1916)
Conditions of subject:
Overnight fast
Overnight restful sleep
2 h rest prior to measure of BMR (07.00–09.00 am)
Thermo-neutral environment
Technical features:
Apparatus of Benedict-Roth modified by Boothby and Sandiford (1924)
VO_2 measured for 8 min in duplicate (or until difference < 2 kcal m^{-2} h^{-1}), at standard temperature, pressure, dry
Measure of stature, weight, body temperature, heart rate, blood pressure of all subjects

Principles adopted in the Italian studies for the measure of BMR

The other cause brought forward to explain the higher BMR values of the Italian subjects had been the dominant presence of highly trained individuals. Indeed, no physiological reason exists why physically fit and muscular people should have a higher BMR. Indeed, factors such as the lower heart rate and the larger proportion of muscles in the composition of the FFM of trained individuals as compared to unfit individuals, would rather conjure against a higher BMR kg^{-1} body weight. A second consideration concerns the statement that the Italian subjects represented an unusually fit and physically very active group. It appears that the evidence was inferred from the job denomination, namely being military subjects. This is only partially supported by a closer look at the data, as it is the 97 Sardinian miners and labourers[22] that have the highest standardised BMR, followed by 70 students of the Naples Royal Military College[19]. The 532 cadets of the Royal Fascist Academy in Rome[18] and the 252 cadets of the Royal Naval Academy in Livorno[23] have the lowest BMR. Moreover, available documentation on the daily schedule of students of the Royal Fascist Academy revealed that they engaged in vigorous exercise only for a very modest amount of time. The military recruits studied by Lenti (525 subjects),[20] have BMR values that are intermediate; this is the most varied group, as it includes small artisans, blue-collars, farmers, students and employees. These individuals were measured shortly after recruitment and there was no selection, besides exclusion for obvious pathologies or exceedingly short stature.

It is interesting to point out that the measured BMR of a contemporary small group of Italian men and women was found to be lower than that of 60–70 years ago[24,25] and was thus overestimated by 7–8% by the Schofield equation. On the other hand the BMR of about 900 elderly Italians (mean age: 76 years) was well predicted by the Schofield equation[26].

In conclusion, no obvious and plausible reasons have been revealed for the higher metabolic rate of the Italian data set included in the Schofield analysis, and they remain an unresolved challenge.

The ethnic factor

The other concern is represented by the observation that the measured rates of BMR of Asian subjects, but also of more generally termed tropical populations, tended to be over-predicted by the Schofield equations[12,15]. Similar results were obtained more recently in Bangladesh[27] and in New Guinea[28]. Racial differences have been described also in African American adolescents, whose adjusted resting energy expenditure (REE), was lower than that of their white peers[29]; similarly, the REE of black adult women was overestimated by about 9% by the Schofield equations, but not that of their white peers[30,31]. A 7% overestimation of the BMR has also been found in 38 Australian young males[32]. This evidence led to hypothesise the existence of an ethnic factor.

However, several other studies conducted on a variety of ethnic groups, provide a different picture, with measured BMRs either similar or higher than predicted[33]. The BMR of Indian men and women were found to be correctly predicted by the Schofield equations, independently of their nutritional status[33]. A later analysis found that Chinese children's BMR is correctly predicted[34]. The same is true for adult Ethiopian men and women[35,36], and for Mexican men[37]. The IDECG report commented that preliminary analyses seemed to indicate a closer prediction by Schofield equations in recent data from Africa, India and China than previously reported[38].

So far, no physiological mechanism has been offered to explain the alleged ethnic difference, although some indirect evidence seems to point to possible environmental and/or phenotypic factors[10]. Chronic energy deficiency (CED) can induce modifications of the composition of the FFM, and/or of body proportions. FFM explains 70–80% of the variability of BMR, thus it has been suggested that changes in its composition, such as changes of the weight of visceral organs, could explain the residual 20–30% of the variability. Differential losses of organs' weights are known to occur in starvation[39] and, in principle, would be capable of modifying the overall energy turnover of the FFM. However, given the earlier loss of low turnover rate muscles, these changes would rather increase BMR per unit of FFM than depress it. A study designed to account for the residual variability of the BMR on the basis of the natural inter-individual variability of visceral organs' size failed to demonstrate an improvement in the prediction of BMR when combining muscle and organs' masses when the prediction was based on the FFM[40]. The authors concluded that this provides an indirect indication that the residual inter-individual variability of BMR might be explained by differences in the energy expenditure per unit of organ. Schofield equations overestimated by 15% the BMR of anorectic young women[41] and that of chronically malnourished adult Indian labourers[42]. However, the subjects of these studies were overtly malnourished and selected specifically on this basis. It would be unjustified to attribute all ethnic-dependent cases of over-prediction of BMR by the Schofield equations to a condition of covert malnutrition.

The ethnic/tropical phenomenon remains, therefore, unresolved, and needs to be corroborated and quantified, but also, and even more importantly, a sound physiological basis must be produced and a plausible mechanism identified.

Adjustment for body size and the limitations of PAL

Adjusting the energy requirement on BMR aims to make it body size independent. However, the use of a ratio requires that the variable at the denominator and that at the numerator be linearly related, with a 0 intercept.

Neither of these assumptions hold true for the relationship between energy expenditure and BMR, thus introducing an error in the expression. These aspects have been investigated in detail in several excellent papers, some of which have appeared since the IDECG meeting, and thus deserve being considered here in some detail. Carpenter and colleagues, in a meta-analysis of 13, carefully screened, studies on the energy expenditure of healthy adults, confirmed the non-0 intercepts and the existence of a large variability in the correlations between energy expenditure measured by DLW and BMR[44]. They concluded that these conditions preclude the expression of energy expenditure as multiple of BMR, and advocated that it be expressed as a function of BMR in a regression-based approach, regretfully not easily feasible.

Prentice and colleagues have shown the need to take into consideration – when adjusting energy expenditure for body size – whether the activity undertaken is or is not weight-dependent[44]. They calculated the exponents of body weight to be used when normalising the energy cost of activities. The exponents range widely from 1 for weight-dependent activities such as climbing stairs or walking speedily, to as low as 0.3 for non-weight-dependent activities such as sitting or lying (see Table 3). They pointed out that the complexity and variety of physical activities undertaken in real life precludes the possibility of recommending one single exponential, and that a number of specifically designed exponents should be elaborated for each specific mix of activities. This obviously would require a reasonable knowledge of the activities undertaken by the various groups whose energy expenditure is to be compared or assessed.

The carry-over effect on PAL of neglecting to normalise body weight with the appropriate exponential was examined in a paper published shortly afterwards[45]. Haggarty and colleagues, examining the issue of the dependence of PAL from body weight, noted the hyperbolic increase in the error of estimate of the energy cost of single activities with increasing body weight, the more strenuous the activities the steeper the error of estimation (Fig. 1)[45]. They quantified the implications of this error, and showed that extrapolating to a 40 kg individual the energy cost of activities measured on a 70 kg individual introduces an overestimate of 0.4 units of PAL for low intensity activities, but that the overestimate would increase to 1.0 PAL units for physically more demanding activities, and climbs up as high as 2.3 PALs for vigorous activities. Symmetric underestimates would occur when PALs measured on a low weight person are applied to larger individuals. They calculated that an overestimate of energy expenditure by 2 × PAL would result in about 10% overestimation for each of the three work categories of the 1985 report[1].

Table 3 Examples of exponents of body weight for diverse weight-bearing and non-weight-bearing activities. These exponents normalise the energy cost of individuals of different body weight and allow meaningful comparisons to be performed[44]

	Exponent
Weight-bearing activities	
Stepping	0.99
Walking 2 mph	0.80
Walking 4 mph	1.05
Non-weight-bearing activities	
Cycling	0.49
Sitting	0.31

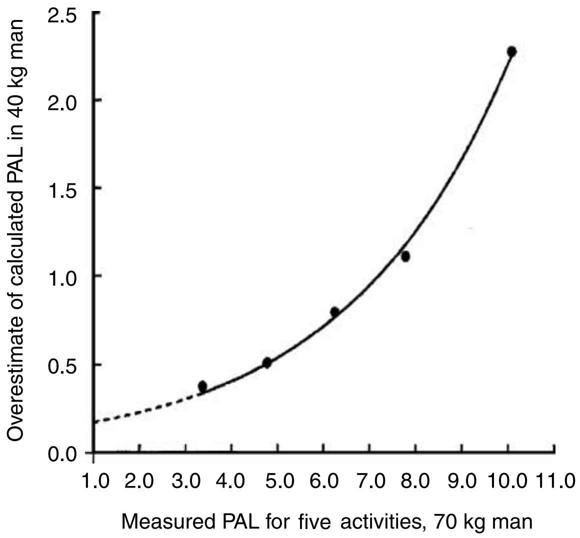

Fig. 1 Example of overestimate of PAL of a 40 kg man engaged in five diverse activities when applying a PAL derived from a 70 kg person. The five activities consist of walking with increasing loads at increasing gradients or jogging at 10 km h (adapted from 45).

These considerations need to be taken into account when deciding the opportunity of retaining or rejecting the PAL approach for the estimation of energy requirements. The right balance must be found between the convenience of using PAL for expressing energy requirements, and the errors that are inherent to this approach. The ideal solution would be to collect a database containing the energy costs of activities measured on individuals of different body mass, and to calculate on this basis a variety of size-adjusted PALs for the diverse and prevailing styles of life and mixture of activities. This is an achievable task, if laboratories worldwide would concentrate their actions to this end. It should be possible to build up, over the next few years, an appropriate, sound and updated database for this purpose.

Requirement for what? The importance of time budgets and energy costs of activities

A plea was made by the IDECG Panel of experts on the need to expand the database relative to the energy costs of activities and the lifestyles[8]. Both these areas of research appear to have fallen, worldwide, out of the interest of scientists involved in research on energy metabolism, possibly in concomitance with the spread of the

DLW methodology. The IDECG document stressed that the main usefulness of the DLW method rests on its capacity 'to corroborate the validity of some of the low activity factors ... which are sometimes found in individuals without apparent reasonable explanation'[11]. The method has recognised limitations in its high costs and the highly specialised expertise and instrumentation that were needed, but Durnin went on commenting that, of all the available methods for measuring energy expenditure, the uniqueness of the DLW technique is that it 'provides no information other than on total energy expenditure over a period of several days'[11].

The '*normative*' estimate of energy requirement – as opposed to the '*prescriptive*' estimate – was adopted by the 1985 report, and was endorsed by the IDECG meeting. It must be recognised that this approach places a heavy responsibility on the scientist and policy maker, as the choice of the '*norm*' must be guided not only by the scientific knowledge of biological facts, such as, for example, how much energy a child needs to catch up and return to his normal channel of linear growth, but also by the judgment of the amount of energy that is appropriate for economically necessary and socially desirable activities under diverse circumstances. Obviously, the latter decision is highly subjective, and an informed decision can be taken only if a number of ancillary, but crucial, contextual information are available. Which means that beside a good understanding of the principles regulating energy metabolism in man, the practical knowledge of the integrated energy cost of activities, leisure and occupational, of how these people use their time, and finally of the socio-economic connotations of everyday life in the specified community, is also needed.

The complexity of the topic is further complicated by the difficulty of distinguishing between low planes of energy expenditure dictated by social or environmental circumstances (such as seasonality and/or unemployment) and those that are expression of a condition of CED (as revealed by a low BMI). Sustained exposure to intakes that do not match energy expenditure prompts a set of various adaptive/coping mechanisms, of a biological and – later – of a behavioural nature in the attempt to save energy and to re-establish a steady state of energy flux through the body, that will be at a lower level of energy expenditure[5]. Obviously, such a reduced/adapted level of energy expenditure does not represent the true requirement of the individual, but represents an adaptive response to a restricted access to energy. Despite this aspect having been widely investigated[5,35,46,47], it remains impossible so far to know *a priori* to what extent a low energy expenditure is the expression of adaptive responses to lack of food, or is driven by socio-economic conditions that are totally unrelated to access to sufficient food energy[49]. This has, necessarily, implications for the '*normative*' estimate of the energy requirement of a population. As opposed to a *status quo* approach, the adoption of a normative approach per force includes a socio-economic dimension that falls outside the physiological context of energy requirement, and is unpredictable. Thus, time budgets and the measure of energy costs of various activities acquire a pivotal importance in the estimate of energy requirement.

Health and physical activity: the need for more clarity

The role played by physical activity in the maintenance of long-term good health and physical fitness has received increasing attention in recent years. Recommendations regarding exercise are now part of national and international dietary guidelines[49,50] and they appear with increasingly more detail on the nature and amount of exercise. This evolution stems from two converging considerations, the first one concerning Western populations and their increasingly sedentary lifestyles[51], the second one being the identification of the role played by low levels of physical activity in the pathogenesis of pathological conditions[52]. Besides its role in the maintenance of physical fitness, muscular tone and motor coordination at all ages, consensus has been reached on the specific involvement of physical activity, as a concurrent or facilitating factor, in obesity, cardiovascular diseases, diabetes mellitus, osteoporosis and colon cancer. A consensus has been reached on the need to maintain a certain level of physical activity to prevent these conditions and, more generally, to protect the health of the general population at all ages. However, the body of scientific evidence on the nature, intensity and duration of the physical activity is still incomplete and should be improved. Aspects such as the long-term compliance, the feasibility of exercising in the modern societal context, the modulation of duration, vigour, frequency of exercise according to the age of the persons are all aspects that should be addressed. Scientific documentation on these aspects is likely to become available in the near future as result of new studies now being conducted will become available. A review of the literature regarding the type of exercise and the prevention of obesity and coronary heart diseases (CHD), has been recently published[53,54].

There is no doubt that these considerations should be taken on board in the revision of the principles on which to base the estimate of energy requirement.

Recommendations

- BMR predictive equations should be reformulated, on the basis of a reviewed and expanded data bank with strict, transparent quality criteria.
- Ethnicity/tropical correction factors should not be incorporated, unless endorsed by unequivocal evidence yet to be produced.

- The approach of expressing energy requirement on the basis of PAL should be retained.
- Energy requirement of children below 10 years should be derived from energy expenditure.
- The factorial approach for estimation of energy requirement should be retained, and be based on objective documentation of actual lifestyles and measured costs of energy.
- Allowance for desirable levels of physical activity for long-term health should be included, possibly re-defined on the basis of emerging evidence on the intensity, frequency and duration of the exercise. Specification as to the context where this inclusion is applicable should be given, especially regarding the emerging transition of the health and lifestyle profiles of the developing world population.
- Explicit and fact-based rationales should be provided to guide policy makers' choices between *normative* and *status quo* options of energy requirement estimates.
- The probability nature of the estimate of adequacy of energy intake should be better clarified for the general public.

Areas for further research

- The alleged ethnicity/tropicality factor needs to be confirmed and better understood. Its physiological or functional basis must be established and a plausible mechanism be elucidated.
- Specialised data banks of the energy cost of most common activities should be created, distinguishing weight bearing from non-weight-bearing activities.
- Exponents for body size normalisation of main mixes of activities should be developed.
- Reliable documentation of the lifestyles and time use of adults, children and elderly people in diverse contexts should be collected, with special effort to include contexts and circumstances proper of developing countries and of transition societies.
- The data bank on the energy cost of a variety of activities undertaken under real life conditions (as opposed to calorimetric measures) by children and adults should be updated and expanded.
- The nature, duration, frequency and intensity of physical exercise required to maintain general good health, and for the prevention of specific pathologies such as obesity, CHD and cancers should be established.

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